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An integrated approach to teaching the topic of *light and colors* from the seventh grade physics syllabus

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The paper presents a variant for integrating knowledge about the physical nature of colors and knowledge about the color as one of the basic artistic means in painting. The performing of real and virtual experiment provides the opportunity to introduce and compare on the qualitative level two different models of gaining color perception: (i) Obtaining light in random color by mixing in different proportions the light beams of three primary colors: red, green and blue; (ii) Obtaining new colors by the mechanical mixing of paints, as in this model the three primary colors are red, yellow and blue. Specific attention is paid to the practical application of the discussed models. The importance of the integrated lessons for the formation of an overall world picture in the students' minds is emphasized.

Keywords: physics education, painting, light, color, integrated approach

INTRODUCTION

According to the current syllabus, the topic of "Light and Colors" (section "Light and Sound") is an important part of the 7th grade *Physics and Astronomy* learning content in junior high school. It is planned to be studied in the framework of two lessons. The main goal is to clarify the physical nature of colors, which is closely related to grasping the new physical concept – *light spectrum*. The curricular of study are: the colors in the spectrum of white light; *the primary colors* and the result of their mixing; the possibilities for changing the white light through color filters and the answer to the question: when and why bodies change their color [1].

The current study was provoked by a common situation in the teaching practice of this particular learning content. When the physics teacher clarifies that *the primary colors are three: red, green and blue*, the students react that this fact contradicts their knowledge acquired in the curricular of art – *the three main colors are red, yellow and blue.* It is obvious that this contradiction must be resolved, and this requires the teacher to be prepared in advance in order to implement an adequate integrative approach in the learning process. This paper presents a methodological suggestion for studying part of the learning content on the topic, which helps students to acquire the necessary knowledge about the physical nature and origin of colors and *to understand and solve the problem themselves*. It is important to note that from a didactic point of view the situation is very favorable, as the modern concept of integration in education involves not only unification, complementing educational elements from different curricular areas, but also creating a product of new quality (idea, meaning, element, etc.) on the basis of *resolving contradictions* [2]. This fact reflects the specifics of integration in learning compared to interdisciplinary links.

As a matter of fact, the literature review shows that neither pedagogical knowledge nor the knowledge of teaching methodologies offers a unanimously accepted definition of the concept of *integration,* as well as the related concepts *integrative approach* and *integrative education.* For the purposes of this study, *interdisciplinary integration in educational practice is considered a process of connecting separate elements (knowledge, relations, evens modes of thought) into a whole by way of meaningful and stable associations, which satisfies a specific educational goal. A new system is formed as a result which has the following main characteristics – continuity and expedience* [3]. The integrative approach combines the paths and means of establishing integration and its realization results in a type of education that can be viewed both as a system and as a process of forming integrative associations.

Up until the middle of the 20th c. the conceptions of integration concern the level of interdisciplinary connections and most authors regard these as [4]:

- a didactic means of increasing the effectiveness of knowledge, skill, and habit acquisition;
- a condition for the development of cognitive activity and autonomy, for the formation of cognitive interests;

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- a means of realizing the principles of systematicity and science or as an independent principle of education;
- a means of achieving unity of mainstream and professional education and forming professional skills;
- as a condition for enhancing the scientific level of knowledge, etc.

Other researchers define interdisciplinary connections as a *didactic phenomenon* reflecting connections between sciences in education; as *a didactic condition* for the provision of coherence among syllabi and course books in various subjects; as a *didactic process* or *principle* pertinent to holistic knowledge of nature and society; as *an independent sphere of didactics* characterized by specific psychological and pedagogical rationale, principles, methods, means used to form qualitatively new knowledge – interdisciplinary one [5].

Scientific literature offers definitions of wider scope which reflect specific characteristics of integration considering it as a process and a result at the same time [6, 7, 8].

Importantly, a large number of researchers side with the idea that the core of integration in education cannot be limited to mechanic amalgamation of inter-subject and intra-subject connections. Unlike interdisciplinary connections, integration implies a transition from coherence in the teaching of different subjects towards their deep interaction. In connection with this idea, it is worth noting the works of M. N. Berulava. He defines three main levels of realization and integration of instructional content [9]:

- the level of interdisciplinary connections – associated with the actualization, generalization and systematicity of knowledge (content integration);
- the level of didactic synthesis – it is characterized not only by the content integration of the subjects, but also by the integration of the forms of educational activity (procedural integration);
- the level of completeness – it ends with the formation of a new subject of an integrative character**.**

The level of didactic synthesis is productive with respect to the improvement of the educational process. It reflects *the interaction* among the subjects taught, gives a comprehensive idea of the objects, phenomena and processes in the surrounding world and aids the realization of person-centered education.

The integrative lesson is among the most commonly used contemporary forms of educational activities which is conducive to the realization of didactic synthesis. The goal of integrative lessons is to achieve high systematicity of the instructional content, to create conditions for multi-faceted consideration of the objects of study solving didactic tasks coming from two or more subjects in the meantime. To plan such a lesson, it is crucial for the teacher to choose the integrative factor correctly – the rationale for the amalgamation of the elements into a unity. The role of such an integrative factor can be fulfilled by a phenomenon, an idea, a concept, an object, a technology, a method, etc. Pertinent to the nature of the present study is the situation when a specific *problem* serves as an integrative factor (integrator) which is related to controversial aspects of the instructional content. In other words, it is the problem that unites, groups heterogeneous content. And it is a widely known truth that involving students in the processes of uncovering and solving educational problems puts them into the shoes of explorers – an important factor improving the characteristics of their overall cognitive and practical activity.

PRACTICAL IMPLEMENTATION OF AN INTEGRATIVE APPROACH IN TEACHING THE TOPIC OF *LIGHT AND COLORS*

When introducing the topic, the teacher needs to emphasize the fact that until the 17th century there had not existed a scientific theory of the origin and nature of colors. The physical foundation of color science was laid by Isaac Newton with the discovery of the spectral composition of light. Therefore, the basis for structuring the learning content on the topic is Newton's experiment from 1671, which ought to be introduced to the students beforehand through a real or virtual experiment. As it is well known, Newton directed a beam of white sunlight at a triangular glass prism. On a screen placed behind the prism, he observed stripes of different colors, flowing from red to purple and arranged in a strictly defined order. Thus he proved that white light is actually a mixture of many colors. He introduced the term "spectrum" – the rays of all colors that are part of white light form the so called *light spectrum*. Here comes the logical question: what is the cause for the observed phenomenon, i.e. why does the glass prism decompose the white light into its constituent colors? From a methodological point of view, it is appropriate to hold a short discussion, using the students' knowledge about the phenomenon of *refraction of light.* The analysis of the experiment shows that in its passing through the glass prism the light is refracted twice: on entering the prism (on the air – glass border) and on leaving it (on the glass –

air border). In addition, it is obvious that the rays of the different colors are refracted differently (at different angles). The screen behind the prism shows clearly that the violet light is refracted the most and the red light the least. In this way the prism separates the rays, i.e. decomposes white light into its constituent colors, and behind it *the light spectrum* is observed. For the better acquisition of this knowledge, it is appropriate to make an analogy between Newton's experiment and the beautiful natural phenomenon of the *rainbow*, explaining the reasons and conditions for its formation.

The next important step is to make students understand that just as white light can be decomposed into its constituent colors, the mixing of all the spectrum colors can produce white light. However, is it possible to achieve this result by mixing a smaller number of colors? How many colors are needed at the least? To answer these questions, the following experiment can be performed [10]. In a darkened room, beams of red, green and blue light emitted by three spotlights simultaneously are directed to the same place on a white screen. A white circle is formed where the rays fall. In the same way, the light beams from any two spotlights can be used and the effect of mixing each pair of colors can be traced. The image of Fig. 1 illustrates this.

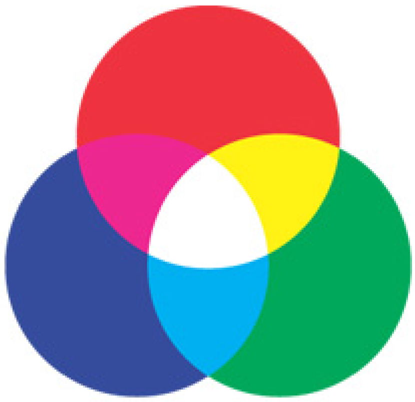

Fig. 1. Additive color mixing – *RGB*-model

Thus, students discover that *white light can be obtained by mixing three spectral colors – red, green and blue.* It is important for the teacher to emphasize that depending on the proportions in which they are mixed, different colors and their shades can be obtained, but *red, green and blue cannot be obtained by mixing other colors.* That is why these three colors are called *primary*. This fact is closely related to the peculiarities of human color vision. Here the teacher needs to explain that the millions of light-sensitive cells that cover the retina of the human eye are responsible for color vision and that they are of three types: some are sensitive to red light, others to green, and still others to blue. Light detectors in these cells are special molecules that receive incoming light signals, convert them into electrical ones and direct them along the optic nerve to the brain. Thus, in the visual center of the brain, our visual perceptions are formed. Therefore, *when red, green, and blue lights enter the eye at the same time, and the contributions of these three primary colors are the same, after processing the signals, the brain forms a perception of white light*. If only two of the primary colors enter the eye at a time, we see respectively: red and green – yellow; red and blue – magenta; blue and green – cyan (Fig. 1). *Yellow*, *magenta* and *cyan* are called *secondary* colors. It is necessary to mention the fact that there is no such combination of primary colors that evokes the perception of black. In this case, *black is the absence of any light falling into the eye.*

Now the students' attention is focused on the following experiment: in three glasses there is the same amount of water, colored in red, green and blue, respectively. Watercolor paints can be used for this purpose. The question is whether mixing the three liquids colored in the primary colors will produce a white liquid. The experiment clearly demonstrates that a black liquid is obtained. *Why is the visual perception obtained as a result of mixing red, green and blue different in the two cases?* Thus, students' attention is focused on clarifying *the basic question*: *how bodies that are not sources of light get their color.* When answering this question, the teacher should remember that, as a rule, we judge the color of bodies when they are illuminated with white light. The following two cases are analyzed:

1) Let us choose a transparent object. In this case, it absorbs some of the colors of the light that falls on it and transmits the rest. *The color of transparent bodies is determined by the color of the light they transmit.* The feature of transparent bodies to transmit light selectively is used in so-called *color filters*. Through them we can *separate* (receive) the light of a certain color from the white light. After perceiving this information, students may realize by themselves that in this experiment we see the liquid in a glass as red, because it absorbs all the colors of light passing through it, and transmits only the red color. The liquid in the second glass is green because it absorbs all the colors of light passing through it, except green. It is the same with the blue color of the liquid in the third glass. When the three liquids mix, they absorb all the light (all colors) and we see a liquid that is black.

2) Let us choose an object that is not transparent. In this case, it *absorbs* some of the colors of the white light that falls on it, and *the components*

reflected in the eye determine its color. *The color of non-transparent bodies is determined by the color of the light they reflect.* Therefore, the red hat reflects only red and absorbs the other colors, the white sheet of paper reflects all colors equally, and the black jacket absorbs all colors. In explaining this learning content, the teacher can use videos of interesting physical experiments that cannot be carried out in the classroom. For example, the experiments with colorful balloons and red laser beam presented in [11] are very attractive. Through a discussion with students, they provoke the answer to a number of questions related to the concept of color from a physical point of view.

As a result of the experiments made so far, the following important conclusions can be drawn:

1. It is not the objects that generate the colors, but the color is the result of the interaction of the objects with the light.

2. No matter whether the bodies are transparent or non-transparent, what is important is the fact that the color of an object depends mainly on which components of white light are *"subtracted"* from it due to absorption.

3. Visual perception when *mixing colors* may be different because it can be formed in different ways:

- by *adding (summing)* colors from white light (additive color mixing)
- by *"subtracting"* colors from white light (subtractive color mixing).

The first option is the case when the light emitted from light sources, such as TV screens, computer monitors, color displays of mobile phones, etc. falls directly into the eye. In such devices, the variety of colors is obtained as a result of superimposition of the three primary colors – red, green and blue in different proportions. This is an additive model of color perception, known in practice as the *RGB*-model (Fig. 1).

The second option is the case when we perceive light not directly from its sources, but the light that is reflected from different objects, as in our perception of works of artists, color photographs, color images in works of printing, etc. This requires the use of subtractive models of color perception, i.e. models that consider the formation of color images based on the "*subtraction*" of colors from white light, in which *the three primary colors are different from those of the RGB-model.* For example, in printing, a model is often used in which *cyan, magenta and yellow* (secondary in the *RGB*-model) *are considered primary colors*. In practice, it is called the *CMY*-model.

After these discussions, the students have the necessary preparation to answer the question why the primary colors in physics are different from the primary colors known from their art classes. They have already realized that the light of any color can be obtained by mixing light beams with three primary colors: red, green and blue. In this case we are talking about the so-called *optical mixing of colors*. However, it is completely different from the *mechanical mixing of colors*, which is realized when we mix paints in different proportions on a palette, canvas or sheet of paper to get new colors. This type of practical activity has been repeatedly performed by the students, creating a variety of drawings. When white light falls on a drawing, some colors are absorbed, while others are reflected, and after a contact with the eyes, the corresponding color perception is formed. Obviously, in this case it is a matter of subtractive mixing of colors, i.e. the color image is obtained by "subtracting" those colors from the white light that are absorbed by the colors in the drawing. As practice shows, in this model of color perception (originated centuries ago) the main colors are *red, yellow and blue* [12].

The image of Fig. 2 illustrates the result of mixing these primary colors.

Fig. 2. Subtractive color mixing – *RYB*-model

It is visible that from blue and red, for example, *purple* is obtained, from yellow and red – *orange*, and from blue and yellow – *green*. These three colors are called *secondary.* From the mixing of *primary* and *secondary* colors, *tertiary* colors are obtained, etc. Another feature is that the mixing of the three primary colors gives a black color. Thus, by using a rich variety of appropriately combined colors, artists create (achieve) the aesthetic and emotional impact of their paintings.

CONCLUSIONS

The proposed teaching strategy regarding part of the topic "Light and Colors" requires the use of information about the practical application of some models of color perception. However, it is important to note that this additional information is not compulsory. Its aim is merely to help students understand and acquire better the knowledge about the physical nature and origin of colors. The proposed teaching suggestion has a significant advantage – it allows students by integrating knowledge from different curricular areas - physics and art, *to resolve a contradiction* they initially face *by themselves*. Such situations are beneficial to the educational process. In this way, students form a complete picture of the world, develop their thinking and increase their motivation to participate in learning.

The elaboration of the conception of education discussed here in view of its practical realization implies the design of a suitable inventory for the evaluation of educational results. Since integrative knowledge and skills are being tackled, it will be highly productive if ways are sought to use the so called *authentic evaluation*, along with traditional methods.

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